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Development of Communication Interface for SSR System Using ARINC 429 and MIL-STD-1553

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***Abstract*— Secondary surveillance radar (SSR) is a radar system used in air traffic control (ATC), that not only detects and measures the position of aircraft i.e. range and bearing, but also requests additional information from the aircraft itself such as its identity and altitude. This military application is called as Identification of Friend or Foe(IFF). CIT is a system comprises of both interrogator and transponder. For both transmitting and receiving Combined Interrogator Transponder(CIT) is used. In order to provide communication between CIT, user control and display unit data transfer protocols are used. ARINC 429 and MIL-STD-1553 are the two protocols that are used in this project for the development of communication among the systems.**

***Index Terms*— Secondary Surveillance Radar (SSR), Identification of Friend or Foe (IFF), ARINC 429, MIL-STD-1553.**

I. INTRODUCTION

A. *SECONDARY SURVEILLANCE RADAR (SSR)*

Secondary surveillance radar (SSR) is a radar system used in air traffic control (ATC), that not only detects and measures the position of aircraft i.e. range and bearing, but also requests additional information from the aircraft itself such as its identity and altitude. Unlike primary radar systems that measure only the range and bearing of targets by detecting reflected radio signals, SSR relies on targets equipped with a radar transponder, that replies to each interrogation signal by transmitting a response containing encoded data. The secondary radar (SSR) is cooperative because it requires the transponder on board the aircraft.

The secondary radar gives three coordinates of the plane:

1. Distance from the sensor
2. Azimuth with respect to a reference direction
3. Information obtained from a dedicated altimeter

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Fig1.1: Secondary Surveillance RADAR

The Principle of Secondary radar is:
The secondary surveillance radar (SSR), with the exception of barometric altitude, is independent because is the ground unit that calculates the distance and azimuth of the plane. The secondary radar system is capable of detecting the presence of aircraft that are equipped with a special unit called Transponder.

B. *IDENTIFICATION OF FRIEND OR FOE(IFF)*

It is the military application of SSR. Identification Friend or Foe (IFF) is a communication based radar system used to identify friendly aircrafts from enemy aircrafts with the help of unique identifier codes. It enables military and national (civilian air traffic control) interrogation systems to identify aircraft, vehicles or forces as friendly and to determine their bearing and range from the interrogator. The IFF system consists of ground or airborne interrogator and airborne transponders fitted in aircrafts. The airborne interrogator transmits pulsed signal with suitable spacing as per the desired mode of interrogation in a specified direction. Aircraft fitted with compatible transponder replies to the interrogation in the form of another coded signal. These coded replies are received by the interrogator and processed for identification. The pulsed communication between interrogator and transponder enables the continuous measurement of range and azimuth of the target. This system when used for civilian Air Traffic Control (ATC) application is called Secondary Surveillance Radar (SSR). As the air-space management needs to be uniform across the world the operation of SSR system is as per the regulation laid down by International Civil Aviation Organisation (ICAO) and **STA**ndard **NA**TO **AG**reement (**STANAG**) 4193.

The system was initially intended to distinguish between enemy and friend but has evolved such that the term

"IFF" commonly refers to all modes of operation, including civil and foreign aircraft use. There are four major modes of operation currently in use by military aircraft plus one sub mode.

- Mode 1 is a non-secure low cost method used by ships to track aircraft and other ships.
- Mode 2 is used by aircraft to make carrier controlled approaches to ships during inclement weather.
- Mode 3 is the standard system also used by commercial aircraft to relay their position to ground controllers throughout the world for air traffic control (ATC).
- Mode 4 is secure encrypted IFF (the only true method of determining friend or foe)
- Mode "C" is the altitude encoder.

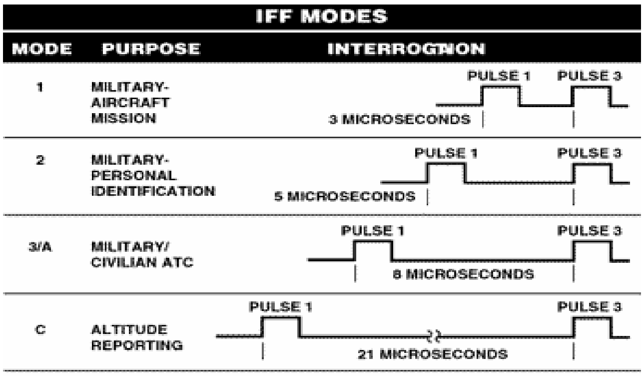


Fig 1.2: Modes of IFF

Each mode of operation elicits a specific type of information from the aircraft that is being challenged. Mode 1, which has 64 reply codes, is used in military air traffic control to determine what type of aircraft is answering or what type of mission it is on. Mode 2, also only for military use, requests the "tail number" that identifies a particular aircraft. There are 4096 possible reply codes in this mode. Mode 3/A is the standard air traffic control mode. It is used internationally, in conjunction with the automatic altitude reporting mode (Mode C), to provide positive control of all aircraft flying under instrument flight rules. Such aircraft are assigned unique mode 3/A codes by the airport departure controller. General aviation aircraft flying under visual flight rules are not under constant positive control, and such aircraft use a common Mode 3/A code of 1200. In either case, the assigned code number is manually entered into the transponder control unit by the pilot or a crew member.

Altitude information is provided to the transponder by the aircraft's air data computer in increments of 100 feet. When interrogated in Mode C, the transponder automatically replies with the aircraft altitude. FAA ground interrogators normally interlace modes by alternately sending Mode 3/A and Mode C challenges thus receiving continuous identity and altitude data from the controlled aircraft.After takeoff, the aircraft soon leaves the departure zone. At this time, the pilot is instructed via radio to contact a specific enroute controller on a specific radio frequency. The enroute controller provides additional flight instructions and may assign a new Mode 3/A code in the event of conflicts in his control zone. On a transcontinental flight, the aircraft passes through dozens of such zones until it is handed over to the approach controller at its destination.

In dense terminal areas, that is, where many aircraft are flying in a small area, the pilot may be asked to "Squawk I/P." The pilot then presses the I/P switch on the transponder which shows up as a unique display and helps pinpoint the aircraft's exact position. Specific Mode 3/A code are reserved to signify aircraft emergencies and radio failures.The code signal sent by the interrogator system consists of two pulses spaced at a precisely defined interval. (A third pulse that has nothing to do with the coding of the query is actually used for interference suppression reasons.) In Mode 1, the interval between the first and last pulse is 3 microseconds; in Mode 2, it is five microseconds; in Mode 3/A, it is eight microseconds; and, in Mode C, it is 21 microseconds. The airborne transponder contains circuitry that discriminates between these various timings and automatically sends back the desired reply.

The transponder replies are also in the form of a pulse, though in this case, there are 12 information pulses that are digitally coded as "ones" and "zeros." The total number of reply code combinations therefore, is 4,096. The reply codes are entered by means of four code wheels on the transponder control unit. The reply pulses generated by the transponder are decoded by the interrogating system and are typically displayed as needed on the primary radar scope near the blip that represents the aircraft that has been challenged. Thus, the aircraft controller can monitor the track of each aircraft through his zone and know its identity, altitude and position at all times.

Most SSR systems rely on Mode C transponders, which report the aircraft pressure altitude. On the ground, the pressure altitude is adjusted, based on local air pressure readings, to calculate the true altitude of the aircraft. Inside the aircraft, pilots use a similar procedure, by adjusting their altimeter settings with respect to the local air pressure. Pilots may obtain the local air pressure information from air traffic control or from the Automatic Terminal Information Service (ATIS). If the transponder is faulty, it may report the wrong pressure altitude for the aircraft.

1.2.1 BLOCK DIAGRAM OF IFF SYSTEM

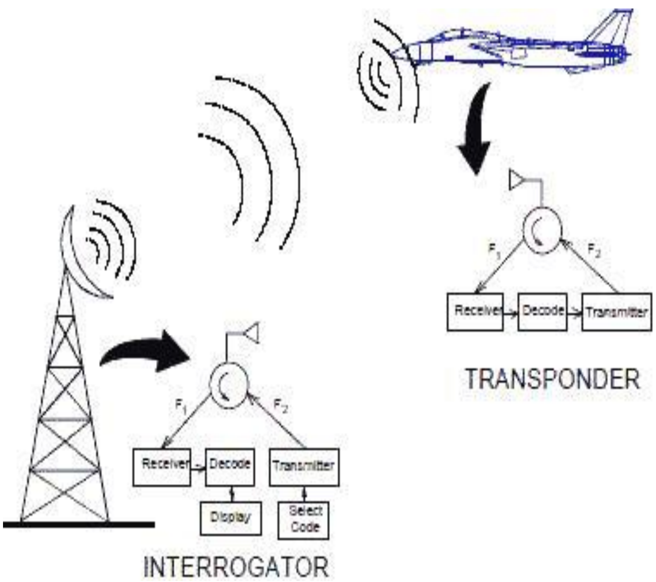


Fig 1.3: IFF Block diagram

1.2.1.1 INTERROGATOR

The SSR Interrogator system consists of the following major sub-systems:
(a)Electronically scanned antenna array
(b)Transmitter-Receiver (Tx-Rx) Unit
(c)Signal Processor(IFF_SP) and Crypto Unit

1) (a)Electronically Scanned Antenna Array

The Electronically Scanned Antenna Array (ESAA) will have two transmit/receive ports. It generates Interrogate and Control Pattern at 1030 MHz in transmit mode while sum and difference pattern at 1090 MHz in receive mode. However the control pattern shall be same as difference beam. The ESAA have the scanning capability of 60 off antenna bore sight to achieve 120˚ azimuth coverage by each antenna. The Electronically Scanned Antenna Array (ESAA) consists of following modules

- Planar Antenna Array
- Distributed Antenna Control Unit (DACU)

The planar antenna array is a 50 x 2 cavity backed slotted array with a dimension of 7.04m x 0.285m occupying the lower portion of 7.04m x 0.9m Integrated PR-SSR Antenna Array of AEW&C system.

The DACU comprises of 10 Beam Controller Unit (BCU), Mode S Electronics & Receiver Unit (MSRU), Monopulse Module and AAAU Controller Unit. The BCU provides the progressive phase shift to the individual radiating elements required for scanning as well as facilitate switching between the dorsal mounted antenna. The Monopulse Module comprises of the 10-way monopulse comparator and two cavity diplexer. The MSRU houses the Dual Channel Monopulse Receiver as well as the electronics required to configure the antenna array for mode S operation. The necessary control signal to the BCU and MSRU is received from the AAAU Controller Unit.

2) (b) Tx-Rx Unit

The Tx-Rx Unit comprises of a Dual channel transmitter that provides a peak power of not less than 2.5 kW. A customized Tx-Rx Controller Card shall be used to monitor the health of transmitter and receiver as well as interface between the signal processor unit, Tx-Rx unit and DACU of electronically Scanned Antenna Array. Also, a customized power supply shall be used to cater for the different input power supply required by various modules. The detailed description of the Tx-Rx unit is provided in subsequent sections.

3) (c) Signal Processor Unit

The Signal Processor hardware comprises of the following hardware VME based COTS board from M/s Curtiss –Wright namely Champ-AV-IV Quad processor board with Rad2 ADC PMC and a customized VME form factor DIO board. The signal processor generates various modes of interrogation. The signal processor also generates the beam pointing angle command for Beam Controller for electronically scanning the antenna beam. The analog signals received from the Tx-Rx Unit are digitized and used for providing target report. It has the capability to decode special signals like emergency, hijack or communication failure. In addition, it also has the capability of distinguishing between two nearby targets and also eliminating the FRUIT (False Replies Unsynchronous In Time). It also monitors the health of the transmitter and the receiver and generates an output giving the health status of the system to be OK or not OK.

1.2.1.2 Diplexer

A diplexer is a passive device that implements frequency domain multiplexing. Two ports (e.g., L and H) are multiplexed onto a third port (e.g., S). The signals on ports L and H occupy disjoint frequency bands. Consequently, the signals on L and H can coexist on port S without interfering with each other.Typically, the signal on port L will occupy a single low frequency band and the signal on port H will occupy a higher frequency band. In that situation, the diplexer consists of a lowpass filter connecting ports L and S and high pass filter connecting ports H and S. Ideally, all the signal power on port L is transferred to the S port and vice versa.

4) 1.2.1.3. Antenna Switching Unit

The airborne targets are generally installed with two Omni-directional antenna for better Coverage on both upper and lower portion of the target. It receives the interrogation signal from both the antenna and compares the signal strength. Depending up on the direction of larger signal, a control signal is generated to switch the transmission through one of the two antennas. This functionality is called the Diversity Reception. For Transponder, the medium power RF SPDT Switch is used for switching in between ANT 1 and ANT 2 for antenna switching operation. In return direction, the received signal routed to the receiver with two SPST RF Switch paths. It's having Five RF connector (one for RF input two connector for RF output and other two connectors for Receiver inputs), a 9 pin D connector for power supply and TTL control for switching the signals.

1.2.1.4 TRANSPONDER

5) (a) Transponder Transmitter

Transmitter shall be used to generate RF reply pulses at 1090 MHz. The solid state transmitter shall be capable of Pulse Amplitude Modulation and provide peak power of 800Watt. and isolator is to be used for protection against the reflected power if not catered for at the output stage of the 800 Watt transmitter. The transmitter shall have protection against over pulse width, higher duty cycle, VSWR faults and provide a status bit for its performance monitoring.

6) (b) Transponder Receiver

Transponder Receiver is a dual channel receiver. It is having two RF input (ANT 1 RF input and ANT 2 RF input) and four video outputs like ANT 1 video, ANT 2 video, ANT 1 BIT stream or ANT 2 BIT stream (BPSK demodulated) which is one higher signal strength with 30 pin DIN connector for power supply, & data interface.

The BITE oscillator is an oscillator. It is having one SMA connector for RF out and one 9pin D-type connector for power supply and data interface.

1.3 Project Objective

This project requires the following tasks to achieve the main objective:

- The main objective of this project is to develop communication interface for SSR systems by using VxWorks Software.
- MIL-STD-1553, ARINC 429 and their word format techniques are used to develop communication among the Avionics.
- After Programming in the software by different formats, we can verify whether the correct communication has been developed or not.

1.4 Literature survey

To fulfill the objectives of the thesis, understanding the fundamentals of RADARs and having Knowledge in C language is essential. "Fundamentals of Radar Signal Processing " by Mark A.Richards, McGraw-Hill Publications is studied to get an overview on RADARs. Several standard books were referred to get clear idea about the Signal Processing in RADARs. In order to understand the standards of MIL 1553 and ARINC 429, I read Reference papers of IEEE Publications.

To get Knowledge in VxWorks, I took the help of Vxworks image processing toolbox . Many technical papers which are added in my References section and books were referred to understand the previous technologies ,to get an overview about implementing my project, in an efficient. Internet material is also utilized for better understanding.

1.5 Organization of thesis

In the chapter 1, I discussed the SSR, Overview of IFF System and various parts of IFF System. In chapter 2, I describe Combined Interrogator Transponder. In chapter 3,I describe the word formats and bit description for MIL 1553 and ARINC 429. In chapter 4 ,I describe the overview of Vxworks Software.

In chapter 5, Experimental Results. In chapter6, I describe the conclusion of my paper.

II. COMBINED INTERROGATOR TRANSPONDER (CIT)

2.1 CIT SYSTEM DESCRIPTION

The IFF CIT is a long range, airborne, Mk XII compatible system having capability to operate to facilitate Interrogator function and Transponder function. This information is very vital in the wartime scenario and is also useful to form database during peace time surveillance. It operates as per the recommendations of Annexere-10 of International Civil Aviation organization (ICAO) and STANAG 4193 interface. The various modes of operation of the IFF Mk XII (S) are 1, 2, 3/A, C, 4 and S (level-2). The interrogator transmits pulsed signal in a particular mode of interrogation in a specified direction. Aircraft fitted with compatible transponder receives the interrogation signal and replies back in the form of another coded signal. These coded replies are received by the interrogator and processed for identification. The replay provides additional target details such as height, range and azimuth and target status like communication Failure, Emergency and Hijack. Mode 4 is an encrypted mode of operation that enhances its capability to be secured, jam resistant and resistant of spoofing. Operation in Mode 'S' (level 2) gives capability of selective addressing and data link capability which are very critical in dense air traffic.

The system generates an out power of 4KW and 1KW for Interrogator and Transponder respectively. The system also consists of a Dual Frequency Dual Channel Monopulse receiver with sensitivity up to -93 dBm which meets the link margin for long range airborne applications. The receiver has been designed using direct detection, making it compact and light weight. The Signal Processor hardware comprises of VME based Champ –AV-IV Quad processor board with Rad2 and MIL-1553 PMC board as modules. All these boards are COTS items from M/s. Curtiss Wright Inc. All these modules/components are designed as per ICAO standard and housed in a single ATR chassis. The block diagram of the IFF CIT is shown below.

2.2 **BLOCK DIAGRAM OF THE IFF CIT**

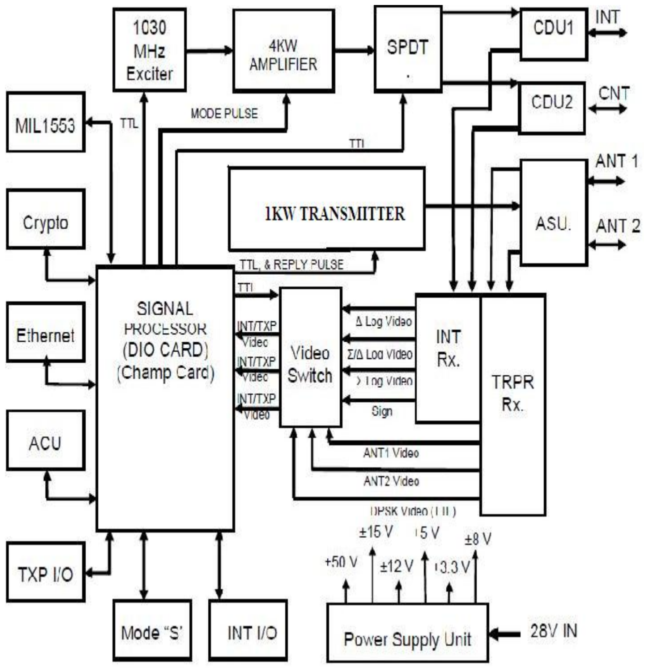


Fig 2.1: Block Diagram of IFF CIT

2.2.1 Sub System Description

2.2.2 Signal Processor (IFF_SP)

The SSR-Signal Processor is implemented using VME architecture. The Signal Processor hardware is consists of

- VME based Champ-AV-IV Quad processor board
- Rad2 ADC PMC
- Customized VME form factor DIO board.
- MIL-STD-1553 PMC board

2.2.2.1 VME based Champ-AV-IV Quad Processor

The Signal Processor of SSR system is being implemented using COTS board which is a standard 6U VME64x board having 4x MPC 7447A with high onboard bandwidth and off board I/O capabilities. The board has PCI-X as its backbone for onboard data movement and has two PMC-X sites. This has Motorola Power PC (7447) based SBC with Ethernet port and has provision for two PMC modules. The power PC board has four RS232 ports each connected to each processor and has an onboard Gb-Ethernet switch connecting all the four Processors and two ports thorough the VME P0/P2 connectors (One RS232 and one Gb-Ethernet will be in face plate of the VME card for commercial grade). The PMC-X Pn4 connector pins (64 pins) are routed to the P0/P2 connectors. These are the onboard I/Os and off board I/Os are provided on the VME card. The block diagram of the processor board is shown below.

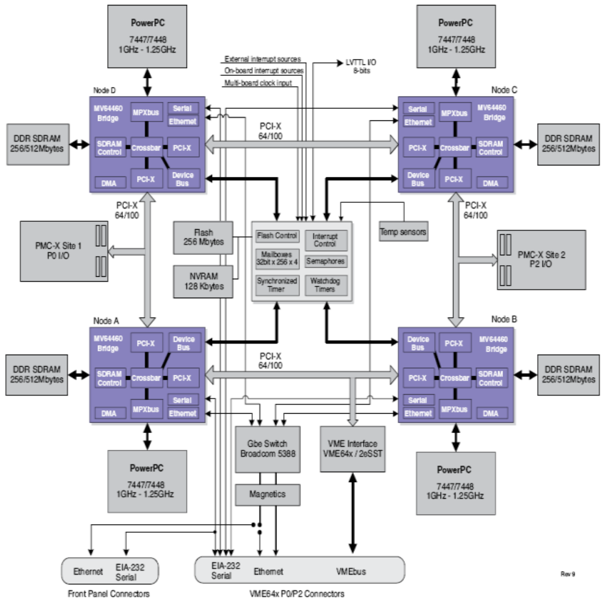


Fig 2.2 : Block Diagram of the Processor Board

2.2.2.2 MIL-STD-1553 PMC board

The **BU-67107M** is a “Multi-IO” PCI Mezzanine Card (PMC) with multiple configuration options. The **BU-67107M** utilizes a PCI interface. The (M) version routes the IO through the rear PN4 connector.

The **BU-67107M** provides new levels of performance and flexibility for systems interfacing to a MIL-STD-1553 or ARINC 429 data bus. There are up to four dual redundant MIL-STD-1553 channels operating in BC, RT, MT, or RT/MT modes, sixteen ARINC 429 receive channels and six ARINC 429 transmit channels, which operate in high/low speed with automatic slew rate adjustment. The card also contains six digital discrete I/Os, an IRIG-B time synchronization input, two RS-422/485 Serial I/O channels, and two RS-232 Serial I/O Channels. The combination of multiple I/O on one card saves valuable PMC sites on host computers and systems. The detailed block diagram of the Mil-1553 card is shown below

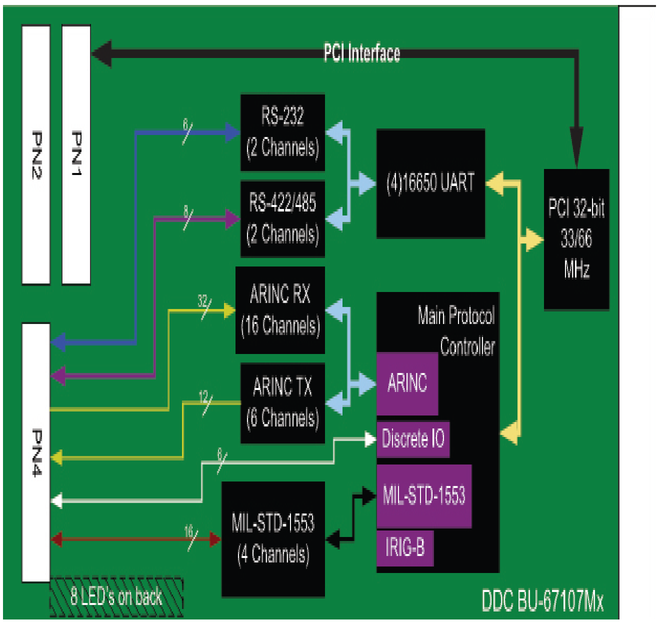


Fig 2.3: Block diagram of MIL-1553 board

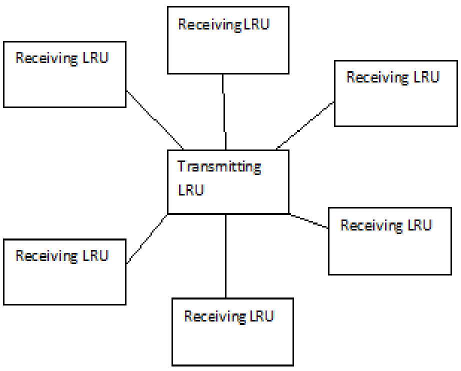
Fig 2.4: Photograph of champ VME Board

III. COMMUNICATION USING ARINC 429AND MIL-STD-1553

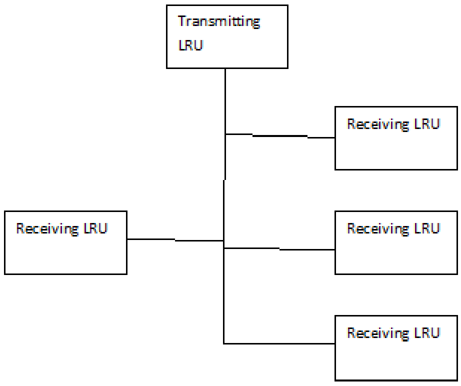
3.1 ARINC 429

ARINC (Aeronautical Radio, Incorporated) 429 is a data transfer standard for aircraft avionics. It uses a self-clocking, self-synchronizing data bus protocol (Tx and Rx are on separate ports). The physical connection wires are twisted pairs carrying balanced differential signaling. ARINC 429, "Digital Information Transfer System (DITS)," is the technical standard for the predominant avionics data bus used on most higher-end commercial and transport aircraft. It defines the physical and electrical interfaces of a two-wire data bus and a data protocol to support an aircraft's avionics local area network. It is a two-wire, point-to-point data bus that is application-specific for commercial and transport aircraft.ARINC 429 defines both the hardware and data formats required for bus transmission. Hardware consists of a single transmitter – or source – connected to from 1-20 receivers _ or sinks _ on one twisted wire pair. Data can be transmitted in one direction only simplex communication – with bi-directional transmission requiring two channels or buses. The devices, line replaceable units or LRUs, are most commonly configured in a star or bus-drop topology. Each LRU may contain multiple transmitters and receivers communicating on different buses. This simple architecture, almost point-to-point wiring, provides a highly reliable transfer of data.

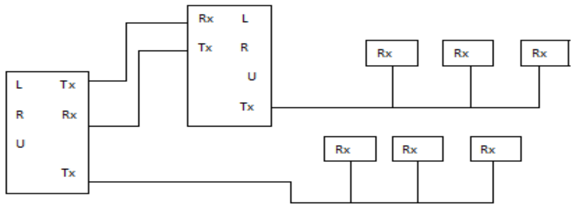
Star Topology



Bus-Drop Topology



Multiple Bus Design



Transmission from the source LRU is comprised of 32 bit words containing a 24 bit data portion containing the actual information, and an 8 bit label describing the data itself. LRUs have no address assigned through ARINC 429, but rather have Equipment ID numbers which allow grouping equipment into systems, which facilitates system management and file transfers.

Sequential words are separated by at least 4 bit times of null or zero voltage. By utilizing this null gap between words, a separate clock signal is unnecessary. Transmission rates may be at either a low speed – 12.5 kHz – or a high speed – 100kHz.

3.1.2 Word Formats

ARINC 429 protocol uses a point-to-point format, transmitting data from a single source on the bus to up to 20 receivers. The transmitter is always transmitting, either data words or the NULL state. Most ARINC messages contain only one data word consisting of either Binary (BNR), Binary Coded Decimal (BCD) or alphanumeric data encoded using ISO Alphabet No. 5. File data transfers that send more than one word are also allowed.

ARINC 429 data words are 32 bit words made up of five primary fields:

- Parity – 1 bit
- Sign/Status Matrix (SSM) – 2 bits
- Data – 19 bits
- Source/Destination Identifier (SDI) – 2 bits
- Label – 8 bits

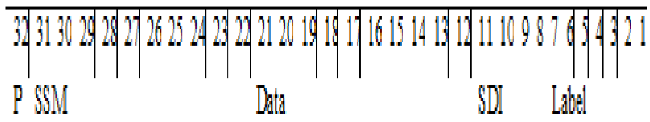


Table 3.1: ARINC 429 32 bit Word Format

The only two fields definitively required are the Label and the Parity bit, leaving up to 23 bits available for higher resolution data representation. Many non-standard word formats have been adopted by various manufacturers of avionics equipment. Even with the variations included, all ARINC data is transmitted in 32 bit words. Any unused bits are padded with zeros.

Parity

ARINC 429 defines the Most Significant Bit (MSB) of the data word as the Parity bit. ARINC uses odd parity as an error check to insure accurate data reception. The number of Logic 1s transmitted in each word is an odd number, with bit 32 being set or cleared to obtain the odd count. ARINC 429 specifies no means of error correction, only error detection.

Sign/Status Matrix

Bits 31-30 are assigned as the Sign/Status Matrix field or SSM. Depending on the words Label, which indicates which type of data is being transmitted, the SSM field can provide different information. (See page 15 for more information on data types.) This field can be used to indicate sign or direction of the words data, or report source equipment operating status and is dependent on the data type.

For Binary Coded Decimal data – **BCD** – the SSM can be used to indicate the sign or direction of the data contained in the ARINC word.

BIT		BCD
31	30	Decoded Information
0	0	Plus,North,Right,East,To,Above
0	1	No computed data
1	0	Functional Test
1	1	Minus,South,West,Left,Down,Below

The No Computed Data code (01) is used to identify a source system that is not able to produce reliable data. The Functional Test code (10) is transmitted with an instruction command to perform a functional test on the receiving unit. When the Functional Test code is received back from the sink, it identifies the data content of the word as containing the results of the test.

When the Label indicates Binary data – **BNR** – bits 31-30 are used to indicate source equipment operating status as shown here.

BIT		BNR
31	30	Decoded Information
0	0	Failure Warning
0	1	No computed data
1	0	Functional Test
1	1	Normal Operation

The Failure Warning code (00) indicates a source system failure that could produce an unreliable data output.The No Computed Data code (01) indicates unreliable data output caused by a condition other than a system failure (which is indicated by using the Failure Warning code).The Functional Test code (10) is used to indicate the word's data contains the results of the functional test.

The use of the Sign function is optional with BNR data and if used, is represented by bit 29.

BNR data SSM Sign Coding

BIT	
29	Decoded Information
0	Plus,North,Right,East,To,Above
1	Minus,South,West,Left,Down,Below

When the Label indicates **Discrete Data** words, bits 31-30 are utilized to report source equipment status using the encoding shown here.

Discrete data SSM Status Coding

BIT		BNR
31	30	Decoded Information
0	0	Verified data,Normal Operation
0	1	No computed data
1	0	Functional Test
1	1	Failure Warning

Data

ARINC 429 defines bits 11-29 as those containing the word's data information. Formatting of the data bits, indeed the entire ARINC 429 word, is very flexible.

When transmitting data words on the ARINC bus, the Label is transmitted first, MSB first, followed by the rest of the bit field, LSB first. Bit transmission order looks like this:

32 | 31 30 29 | 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 | 10 9 | 8 7 6 5 4 3 2 1

P SSM Data SDI Label

Table 3.2: ARINC 429 32 bit Word Format

8 7 6 5 4 3 2 1 | 9 10 | 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 | 30 31 | 32

Label SDI Data SSM P

Table 3.3: ARINC 429 Word Transfer Order

The Label is always transmitted first, in reverse order to rest of the ARINC word –a compensation for compatibility with legacy systems. The receiving LRU is responsible for data translation and regrouping of bits into proper order.

Data Types

BNR Data

Binary, or BNR, encoding stores data as a binary number. Bit 29 is utilized as the sign bit with a 1 indicating a negative number – or South, West, Left, From or Below. Bit 28 is then the data's Most Significant Bit (MSB), or ½ of the maximum value of the defined parameters scale factor. Bit 27 is ½ the value of Bit 28 or ¼ of the scale factor. Bit 26 is ½ the value of Bit 27 or 1 /8 the scale factor and so on.

32 | 31 30 29 | 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 | 10 9 | 8 7 6 5 4 3 2 1

P SSM Data SDI Label

Table 3.4: ARINC 429 BNR Word Format

BCD Data

Binary Coded Decimal, or BCD format uses 4 data field bits to represent each decimal digit. Up to 5 subfields can be utilized to provide 5 binary values, with the Most Significant subfield containing only 3 data field bits (for a maximum binary value of 7). If the Most Significant digit is greater than 7, bits 27-29 are padded with zeros and the second subfield becomes the Most Significant digit allowing 4 binary values instead of 5 to be represented. The SSM field is used to provide the sign of the value.

32 | 31 30 | 29 28 27 | 26 25 24 23 | 22 21 20 19 | 18 17 16 15 | 14 13 12 11 | 10 9 | 8 7 6 5 4 3 2 1

P SSM Digit 1 Digit 2 Digit 3 Digit 4 Digit 5 SDI Label

Table 3.5: ARINC 429 BCD Word Format

Discrete Data

Discrete data can be made up of BNR and/or BCD data, or as individual bits representing specific equipment conditions. Pass/Fail, Activated/Non-Activated and True/False conditions relating to system or subsystem operational activity can be represented by setting or clearing predefined bits in the word data field.

Maintenance Data and Acknowledgement

Maintenance Data and Acknowledgement implies duplex or two-way communication between source and sink. Since ARINC 429 only provides for one-way simplex transmission, two ARINC channels are required for an LRU to send and receive data.

Source/Destination Identifier

The Source/Destination Identifier – SDI – utilizes bits 9-10 and is optional under the ARINC 429

Specification. The SDI can be used to identify which source is transmitting the data or by multiple receivers to identify which receiver the data is meant for.
For higher resolution data, bits 9-10 may be used instead of using them as an SDI field. When used as an Identifier, the SDI is interpreted as an extension to the word Label.

Label
Bits 1-8 contain the ARINC label known as the Information Identifier. The Label is expressed as a 3 digit octal number with receivers programmed to accept up to 255 Labels. The Label's Most Significant Bit resides in the ARINC word's Least Significant Bit location.

Label Bit Structure

	LSB			MSB				
BIT	8	7	6	5	4	3	2	1
Octal Value	4	2	1	4	2	1	2	1

The Label is used to identify the word's data type (BNR, BCD, Discrete, etc) and can contain instructions or data reporting information. Labels may be further refined by utilizing the first 3 bits of the data field, Bits 11-13, as an Equipment Identifier to identify the bus transmission source. Equipment IDs are expressed in hexadecimal values.

For example, BNR Label 102 is Selected Altitude. This data can be received from the Flight Management Computer (Equipment ID 002 Hex), the DFS System (Equipment ID 020Hex) or the FCC Controller (Equipment ID 0A1 Hex).

The Label is always sent first in an ARINC transmission and is a required field, as is the Parity bit. Labels are transmitted MSB first, followed by the rest of the ARINC word, transmitted LSB first.

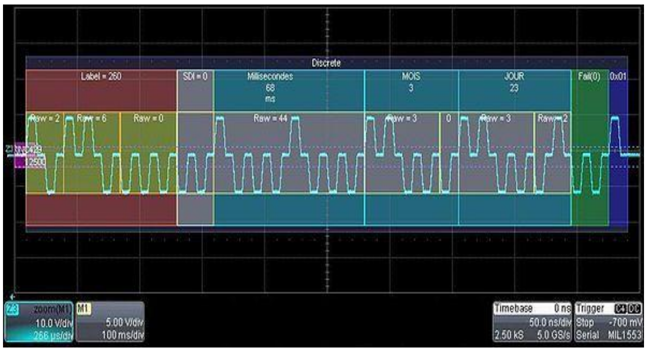


Fig 3.1: Waveforms indicating the ARINC word format

3.2 MIL-STD-1553

MIL-STD-1553 is a military standard published by the United States Department of Defense that defines the mechanical, electrical, and functional characteristics of a serial data bus. It was originally designed as an avionic data bus for use with military avionics, but has also become commonly used in spacecraft on-board data handling (OBDH) subsystems, both military and civil. It features multiple (commonly dual) redundant balanced line physical layers, a (differential) network interface, time division multiplexing, half-duplex command/response protocol, and up to 31 remote terminals (devices).

All communication on the bus is under the control of the bus controller using commands from the BC to the RTs to receive or transmit. The sequence of words for transfer of data from the BC to a terminal is

master.command(terminal) →
terminal.status(master) → master.data(terminal) →
master.command(terminal) →
terminal.status(master)

and for terminal to terminal communication is

master.command(terminal_1) →
terminal_1.status(master) →
master.command(terminal_2) →
terminal_2.status(master) →
master.command(terminal_1) →
terminal_1.data(terminal_2) →
master.command(terminal_2) →
terminal_2.status(master)

The Command Word is built as follows. The first 5 bits are the Remote Terminal address (0–31). The sixth bit is 0 for Receive or 1 for Transmit. The next 5 bits indicate the location (sub-address) to hold or get data on the Terminal (1–30). Note that sub-addresses 0 and 31 are reserved for Mode Codes. The last 5 bits indicate the number of words to expect (1–32). All zero bits indicate 32 words. In the case of a Mode Code, these bits indicate the Mode Code number (e.g., Initiate Self Test and Transmit BIT Word).

Remote Terminal address(0-31)					Receive or Transmit	Location(sub-address) of data(1-30)					Number of words to expect (1-32)				
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

Table 3.6: Command word Bit Usage

The Status Word decodes as follows. The first 5 bits are the address of the Remote Terminal that is responding. The rest of the word is single bit condition codes. Some bits are reserved. A 'one' state indicates condition is true; Message Error and Service Request are examples. More than one condition may be true at the same time.

Remote Terminal address					Single bit condition codes
1	2	3	4	5	6-16

Table 3.7: Status Word Bit Usage

Also as explained above, devices have to start transmitting their response to a valid command within 4–12 microseconds. In the example, the Response Time is 8.97 us, therefore within specifications. This means that the Remote Terminal (RT) number 3 has responded to the Bus Controller query after 8.97 us. The amplitude of the query is lower than the amplitude of the response because the signal is probed at a location closer to the Remote Terminal.

In the Status Word, the first 5 bits are the address of the Remote Terminal that is responding, in this case 0x3. A correct Transfer exhibits the same RT address in the Command Word as in the Status Word.

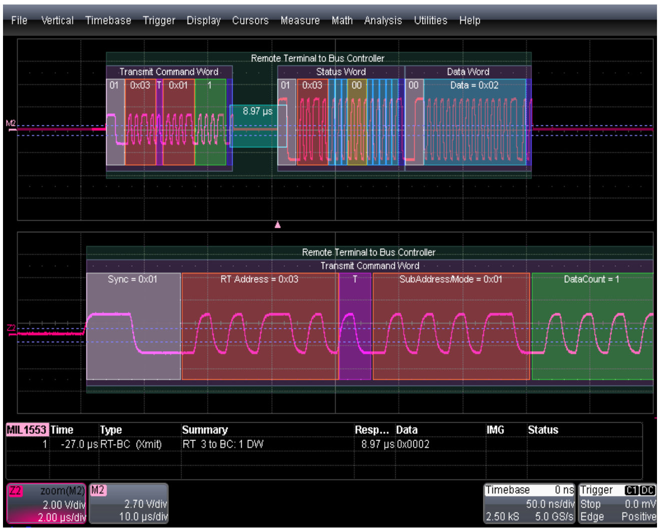


Fig 3.3: Waveforms indicating the bit format

3.3 IRIG Timecode

Inter-range instrumentation group time codes, commonly known as IRIG time codes, are standard formats for transferring timing information. Modern day electronic systems such as communication systems, data handling systems, and missile and spacecraft tracking systems require time-of-day and year information for correlation of data with time. Serial formatted time codes are used to efficiently interface the timing system output with the user system. Both the Standards ARINC 429 and MIL 1553 makes use of the IRIG time codes.

Standardization of time codes is necessary to ensure system compatibility among the various ranges, ground tracking networks, spacecraft and missile projects, data reduction facilities, and international cooperative projects. These digital codes are typically amplitude modulated on an audio sine wave carrier or transmitted as fast rise-time TTL signals. The use of the IRIG standard is to provide a standard protocol for serial time codes that are generated for correlation of data with time.

3.3.1 Time Codes

The different time codes defined in the Standard have alphabetic designations. A, B, D, E, G, and H are the standards currently defined by 200-04.

C was in the original specification, but was replaced by H.

The main difference between codes is their rate, which varies between one pulse per second and 10,000 pulses per second.

Code	Bit rate	Bit time	Bits per frame	Frame time	Frame rate
A	1000HZ	1ms	100	100ms	10HZ
B	100HZ	10ms	100	1000ms	1HZ
D	1/60HZ	1 minute	60	1 hour	1/3600HZ
E	10HZ	100ms	100	10s	0.1HZ
G	10kHZ	0.1ms	100	10ms	100HZ
H	1Hz	1s	60	1 minute	1/60HZ

Table 3.8: IRIG Timecode

Modulation type

1. (DCLS) Direct Current Level Shift (width coded)
2. Sine wave carrier (amplitude modulated)
3. Manchester modulated

Carrier frequency

1. No carrier (DCLS)
2. 100 Hz (10 ms resolution)
3. 1 kHz (1 ms resolution)
4. 10 kHz (100 μs resolution)
5. 100 kHz (10 μs resolution)
6. 1 MHz (1 μs resolution)

Coded expressions

Binary-coded decimal day of year, hours, minutes, and (for some formats) seconds and fractions are always included. Optional components are:

- Year number (00–99; century is not coded)
- User-defined "control functions" occupying bits not defined by IRIG
- "Straight binary seconds", a 17-bit binary counter that counts from 0 to 86399.

1. BCD, CF, SBS
2. BCD, CF
3. BCD
4. BCD, SBS
5. BCD, BCD_Year, CF, SBS
6. BCD, BCD_Year, CF
7. BCD, BCD_Year
8. BCD, BCD_Year, SBS

The recognized signal identification numbers for each format according to the standard 200-04 consist of:

Format	Modulation Type	Caier Frequency	Coded Expression
A	0,1,2	0,3,4,5	0,1,2,3,4,5,6,7
B	0,1,2	0,2,3,4,5	0,1,2,3,4,5,6,7
D	0,1	0,1,2	1,2
E	0,1	0,1,2	1,2,5,6
G	0,1,2	0,4,5	1,2,5,6
H	0,1	0,1,2	1,2

Table 3.9: Permissible Code Formats

Thus the complete signal identification number consists of one letter and three digits. E.g. the signal designated as B122 is deciphered as follows: Format B, Sine wave (amplitude modulated), 1 kHz carrier, and Coded expressions .

The most commonly used of the standards is IRIG B, then IRIG A, then probably IRIG G. Time code formats directly derived from IRIG H.For example, one of the most common formats, IRIG B122: IRIG B122 transmits one hundred pulses per second on an amplitude modulated 1 kHz sine wave carrier, encoding information in BCD. This means that 100 bits of information are transmitted every second. The time frame for the IRIG B standard is 1 second, meaning that one data frame of time information is transmitted every second. This data frame contains information about the day of the year (1–366), hours, minutes, and seconds. Year numbers are not included, so the time code repeats annually. Leap second announcements are not provided. Although information is transmitted only once per second, a device can synchronize its time very accurately with the transmitting device by using a phase locked loop to synchronize to the carrier. Typical commercial devices will synchronize to within 1 microsecond using IRIG B timecodes.

3.3.2 Time Code Structure

IRIG time code is made up of repeating frames, each containing 60 or 100 bits. The bits are numbered from 0 through 59 or 99.At the start of each bit time, the IRIG time code enables a signal (sends a carrier, raises the DC signal level, or transmits Manchester 1 bits). The signal is disabled (carrier attenuated at least 3×, DC signal level lowered, or Manchester 0 bits transmitted), at one of three times during the bit interval:

- After 0.2 of a bit time, to encode a binary 0
- After 0.5 of a bit time, to encode a binary 1
- After 0.8 of a bit time, to encode a marker bit

Bit 0 is the frame marker bit P_r. Every 10th bit starting with bit 9, 19, 29, ... 99 is also a marker bit, known as position identifiers P_1, P_2, ..., P_9, P_0. Thus, two marker bits in a row (P_0 followed by P_r) marks the beginning of a frame. The frame encodes the time of the leading edge of the frame marker bit.

All other bits are data bits, which are transmitted as binary 0 if they have no other assigned purpose.

Generally, groups of 4 bits are used to encode BCD digits. Bits are assigned little-endian within fields.

- Bits 1–4 encode seconds, and bits 6–8 encode tens of seconds (0–59)
- Bits 10–13 encode minutes, and bits 15–17 encode tens of minutes (0–59)
- Bits 20–23 encode hours, and bits 25–26 encode tens of hours (0–23)
- Bits 30-33 encode day of year, 35-38 encode tens of days, and bits 40–41 encode hundreds of days (1–366)
- Bits 45–48 encode tenths of seconds (0–9)
- Bits 50–53 encode years, and bits 55–58 encode tens of years (0–99)
- Bits 80–88 and 90–97 encode "straight binary seconds" since 00:00 on the current day (0–86399, not BCD)

In IRIG G, bits 50–53 encode hundredths of seconds, and the years are encoded in bits 60–68.

Not all formats include all fields. Obviously those formats with 60-bit frames omit the straight binary seconds fields, and digits representing divisions less than one frame time (everything below hours, in the case of IRIG D) are always transmitted as 0.

No parity or check bits are included. Error detection can be achieved by comparing consecutive frames to see if they encode consecutive timestamps.

Unassigned 9-bit fields between consecutive marker bits are available for user-defined "control functions".

IV. EXPERIMENTAL RESULTS

4.1 BLOCK DIAGRAM OF TEST SET UP

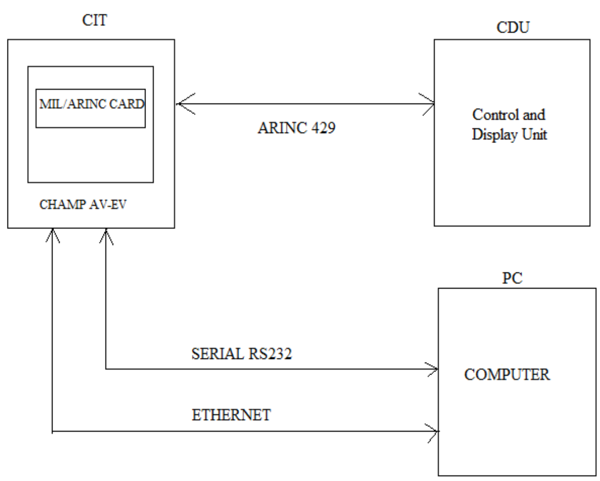


Fig 4.1: Block diagram of test setup

Fig 4.2: Photograph of the Test Setup

4.2 RESULTS

In this chapter, experimental findings using the hardware discussed in Chapter 2 and using the specific methods described in Chapters 3 and 4 are presented.

As discussed in the chapter 3, during the transmission of the ARINC word Label will be transmitted first. Depending upon the status of the bits either they are set or clear a particular format is selected.

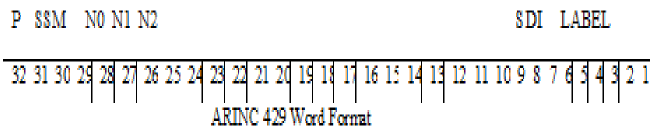
The worked out Labels are as follows:

1. Format for selection of operating mode using rotary switch(Label 202)
2. Format for selection of Reply mode(Label 101)
3. BIT Commands operation(Label 222)
4. Altitude data(Label 375)

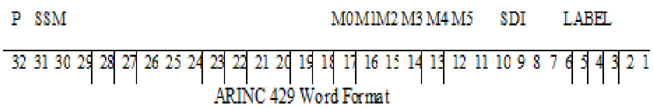
The information transmitted or received to/from the module is identified through the Label which consists of the particular Equipment ID.

Some of the descriptions of the labels are as follows:

1.Format for selection of operating mode using rotary switch

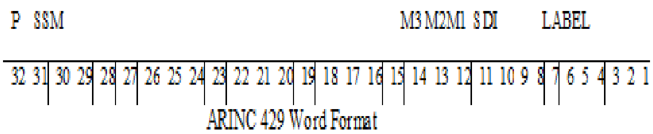


2. Format for selection of Reply mode



If M0=1then it selects Mode 1
If M1=1then it selects Mode 2
If M2=1then it selects Mode 3/A
If M3=1then it selects Mode 4
If M4=1then it selects Mode C
If M5=1then it selects Mode S

3. Reply code Selection



M3	M2	M1	Mode of Operation
0	0	0	No Mode
0	0	1	Mode 1
0	1	0	Mode 2
0	1	1	Mode 3/A

Table 4.2: Selection of reply code

The output can be observed on the target console:

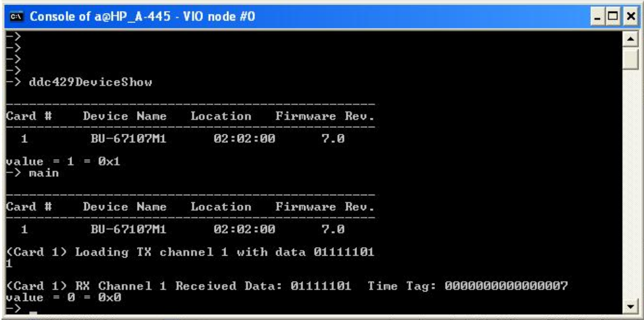


Fig 4.3: Output indicating the communication between boards

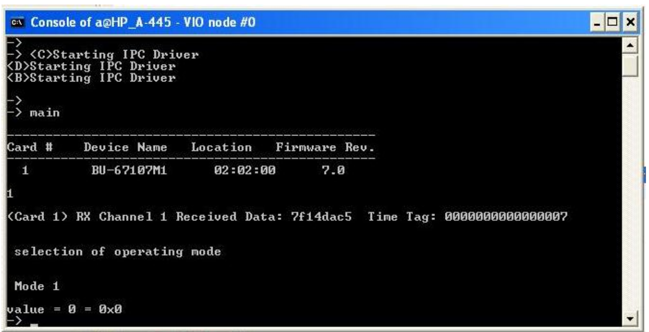


Fig 4.4: Output for the Label(202)

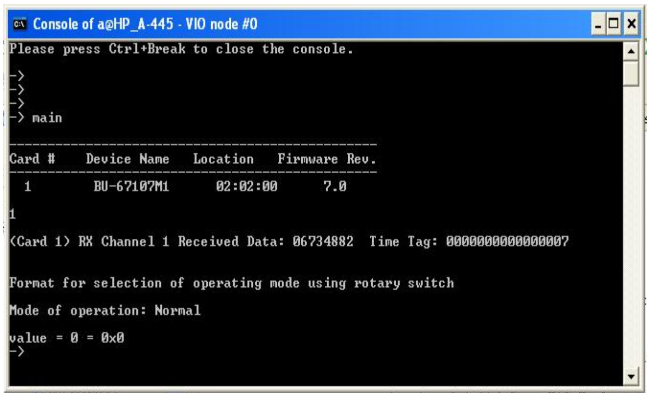


Fig 4.5: Output for the Label(101)

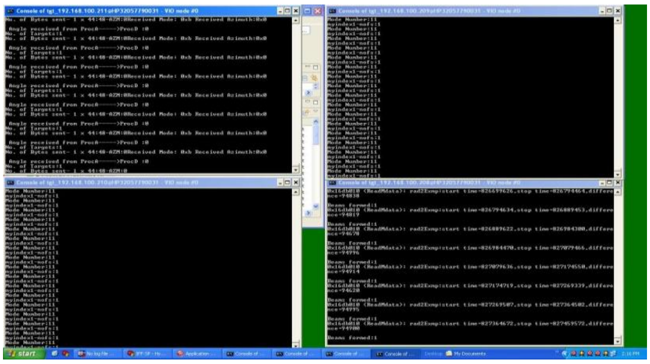


Fig 4.6: Output indicating IRIG Time tag

V. CONCLUSION

Communication interface has been developed using ARINC 429 protocol and MIL-STD-1553B protocol. The software coding was done in 'C' language using Real time operating system VxWorks. Communication under various test condition were evaluated. The communication between control and display unit and processor of the Combined Interrogator Transponder (CIT) were successfully established.

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